3 Software Defined Radio Technologies

3-1 Software Defined Radio for Next Generation Seamless Mobile Communication Systems

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In this paper, the configuration of the newly developed small-size software defined radio terminal for new generation seamless mobile communication systems is introduced. The terminal consists of a common platform that includes an original FPGA board, a CPU board, and RF boards with open interface. Users have only to prepare software modules for FPGAs and CPUs that can configure mobile communication systems that users hope to operate. In addition, the common platform has a control software that can change several communication systems as users like by using several algorithms based on certain conditions. On the common platform, the software modules of W-CDMA and IEEE802.11a that realize physical layer, data-link layer, and network (TCP/IP) layer has been established.

Keywords
Cognitive radio, Software radio, Research and development items, Network, Platform

1 Introduction

In Japan, the total number of subscribers to cellular mobile communication (based on the use of cellular phones and PHS) surpassed 85 million as of February 2004[1]. This means that the method of communication has become established among its users as a way to not only communicate between users, but also to access audio applications and the resources of the Internet, in any place and at any time they please. In addition to cellular mobile communications, other forms of wireless access systems such as wireless LANs, which employ 2.4-GHz, 5-GHz, and 25-GHz-bands, and the FWA (Fixed Wireless Access) system, which employs the 22-GHz, 26-GHz, and 38-GHz bands at transmission speeds exceeding 100 Mbps has been popular as offering users with low mobility broadband communication.

In the future, these systems will make a variety of wireless access systems available to the users; currently, however, it is difficult for a user to carry around the terminals required to access all available systems. Further, methods have yet to be established for communications between different wireless access systems and/or multiple wireless communication systems.

In order to permit communication of the required quality with today's multiple coexisting communication systems, it will be necessary to transmit the volumes of information requested by the user to another party by selecting the most appropriate communication line—whether wired or radio-based—within the time allowed for the communication, based on conditions such as the user's location, the traffic conditions of the given frequency (i.e., level of interference and received signal intensity) at that location, and the user-defined requirements for the mobile terminal (for example, cost effectiveness and low power consumption).

A “new-generation mobile communication system” allows the construction of a mechanism enabling a terminal to identify the conditions of its environment autonomously in the presence of multiple communication systems, to select an appropriate communication system according to this identification within the body of the mobile terminal, and to perform seamless communication between multiple systems using this mechanism. The technology considered essential in the realization of this new-generation mobile communication system is referred to as “software defined radio technology”.

Since around 1995[2], the effectiveness of the software defined radio technology has been proven in operations such as upgrades to eliminate bugs discovered in communication instruments and reducing storage space required for radio terminals[3][4]. At NICT, we succeeded in the development of software defined radio terminals for so-called Intelligent Transport Systems (ITS), which allow communications on multiple systems via a single radio terminal by simply switching among software for PHS, GPS, and electronic toll collection (ETC) systems (as of September 1999), as well as for ETC, GPS, AM/FM broadcasting, FM multiplex telecasting, and VICS applications (as of September 2001)[3]. However, in order to establish a complete new-generation mobile communication system, we were faced with the challenge of building a radio terminal with built-in mechanisms for assessing the environment of radio-wave use and for high-speed switching between communications software. This terminal also had to be able to handle the massive signal processing associated with third-generation cellular and wireless LAN systems on a reconfigurable signal-processing platform with general-purpose, open specifications allowing free configuration of the required communication modes (i.e., an open-platform environment).

NICT has succeeded in the development of just such an open platform featuring the above mechanisms and has also developed a software radio terminal that can perform seamless handover between multiple communication systems simply by switching among software modules within a single mobile terminal. As for the software modules, two kinds of programs have been prepared as communication systems. One is the software that performs the processing function of the W-CDMA system as a third-generation cellular system and the other performs the processing function of the IEEE802.11a/b as a wireless LAN system. The present radio terminal is also capable of receiving digital terrestrial TV broadcasting, again merely by switching the software. This article will present an overview of the developed radio terminal.

2 Summary of software defined radio technology

Figure 1 presents a conceptual diagram of software radio technology[4]-[6]. The software radio terminal is essentially composed of a radio-frequency-band (RF) radio signal-processing unit consisting of RF circuits (such as the antenna, the up-converter, and the down-converter), an intermediate frequency (IF) radio signal-processing unit (consisting of IF circuits such as the quadrature modem and A/D converter), and a digital signal-processing unit (consisting of the D/A converter, an FPGA, and a digital signal processor). The RF and IF radio signal-processing units are sometimes integrated into a single unit, and are referred to as the “radio signal-processing unit”.

In order to perform system switchover, it will be necessary to create a program module to perform the functions of the desired wireless communication system using the digital signal-processing hardware of the mobile terminal, and to input the software module

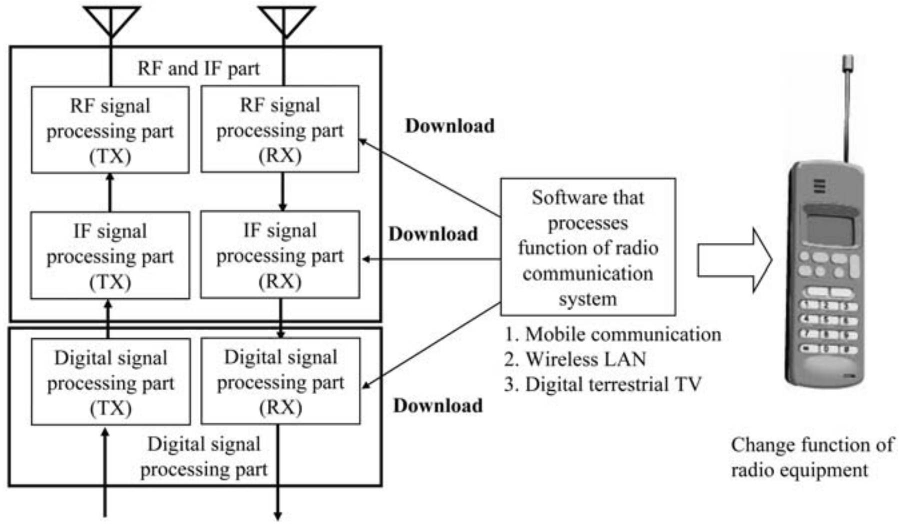

Fig.1 Conceptual diagram of software defined radio technology

accordingly to the digital signal-processing unit from an external controller, in order to implement the desired communication/broadcasting configuration. Further, information on the switching process must also be supplied to the radio signal-processing unit simultaneously, so that adjustments can be made to receive and transmit the signals within the desired wireless communication scheme. By preparing multiple types of such software modules—e.g., for cellular phone radio terminals, wireless LANs, and digital terrestrial TV receivers—and allowing these modules to be downloaded as needed to the mobile terminals for reconfiguration, we will have effectively arrived at a multi-functional mobile terminal.

Fig.2 View of developed software radio terminal

3 Summary of the prototype radio terminal

Figure 2 presents a view of the developed prototype radio terminal. The prototype consists of a software radio terminal (unit on right), which performs transmission and reception processing of radio signals, and a display unit (unit on left), which outputs and displays (in video, still-image, and/or audio format) the signals received by the radio terminal in TCP/IP packet format, as well as converting the captured video, still-image, or audio signals into TCP/IP format and then transferring these to the signal processing unit. Inside the software defined radio terminal is an open platform composed of a digital signal-processing unit (consisting of an FPGA board developed independently by NICT and a CPU board with the μITRON as its OS) and a radio signal-processing unit consisting of an RF board having an interface with publicized specifications (Fig. 3). Figure 4 shows the connections between these boards. This prototype can implement the user's desired communications systems simply by supplying the software module for the FPGA, CPU, and RF boards corresponding to each system. Further, several modules are now ready for use for system switching, based on the environmental

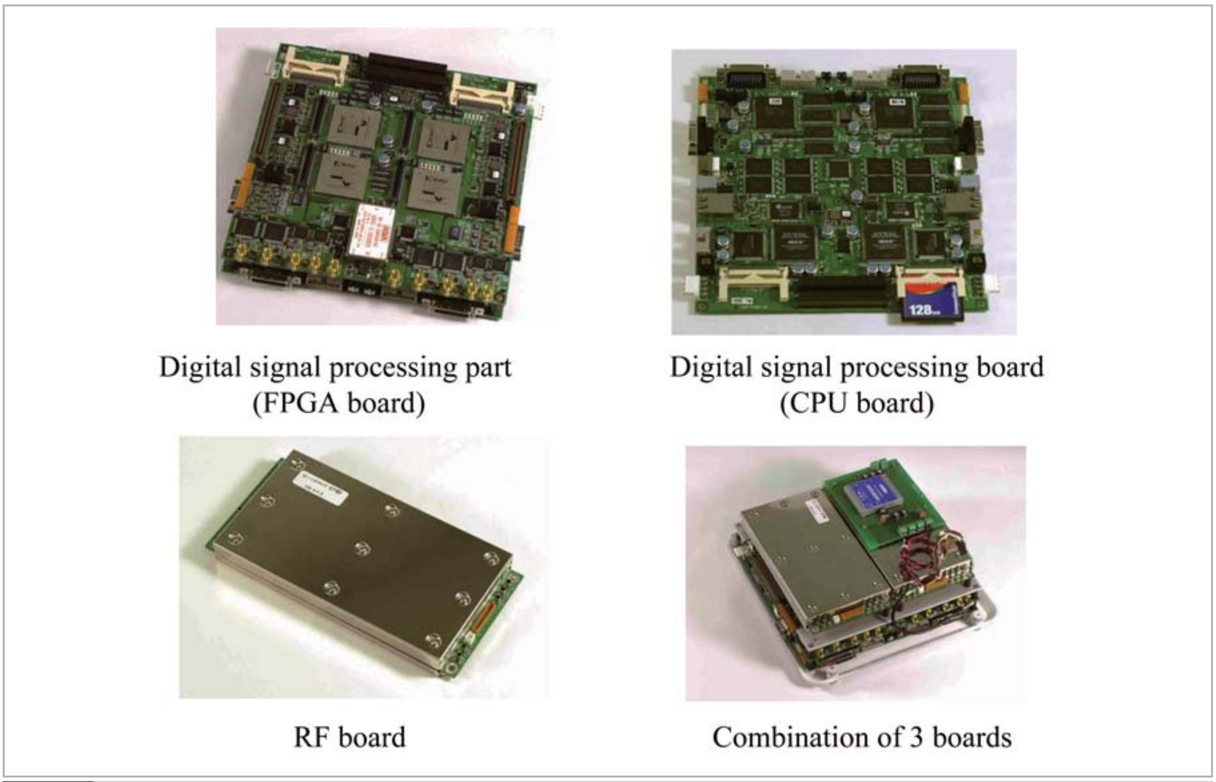

Fig.3 *Signal-processing boards making up the prototype radio terminal*

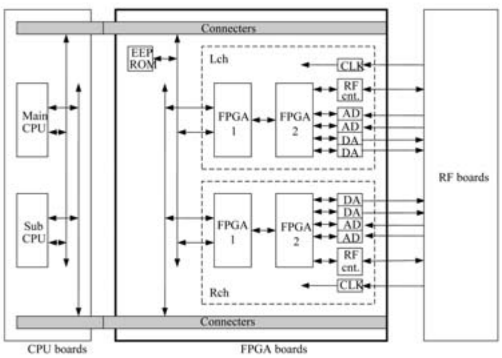

Fig.4 *System diagram of the boards ("RF cont". represents the radio signal-processing controller)*

Table 1 *Basic specifications of each of the developed boards*

Item	Requirement
FPGA board	
ADC	2ch/170 Msps/12bit/0dBm input
DAC	2ch/500 Msps/12bit/0dBm output
FPGA	Xilinx XC2V4000,6000,8000 (selectable)
IF to RF board	Analog in (2ch)/Analog out(3ch)/Cont(5bit)
External clk I/F	Input 5M-66MHz, 0dBm 2,4,8,16 times clk generate automatically
External output	CPU-IF (Max 80Mbyte/s) External output(Max 600Mbyte/s)
CPU board	
CPU	430 MIPS(240MHz)×2
OS	μ-ITRON (PrKERNELv4)
I/O	Compact Flash, RS232C,USB,Ethernet/JTAG
RF boards	5 GHz band board + 2 GHz band board+VUHF board

information required under various communication systems.

The FPGA board has the features shown in Table 1. The board provides output to the high-speed AD/DA converter and RF board and a 600-Mbyte/s, high-speed I/F, dedicated external output to the CPU, and performs all processing in Layer 1. As shown in Fig. 4, a single system is created by software modules for the two FPGAs, and at least two communication systems may be operated simultaneously on the FPGA boards. On the other hand, the CPU board features the specifications shown in Table 1 ; to enable the use of this board in mobile terminals, it is constructed with two CPUs that operate on 430 MIPS μITRON and features various I/Fs. Further, newly produced software can now carry out the functions required for W-CDMA and IEEE802.11a/b wireless LAN, below the IP layer, on this plat-

Table 2 *Specifications and capacities of the software*

Name of module	Requirement／Volume(byte)／Number of FPGA slices
CPU-OS	210k(Main-CPU) / 193k (sub-CPU)
System Selection /TCP-IP	583k(Main-CPU)/ 219k(sub-CPU)
W-CDMA	2GHz band、64kbps/384kbps
	2.214M(sub-CPU) 3.217M(FPGA1)/2.668M(FPGA2)
	72268 (Xilinx VertexII)
IEEE802.11a	5GHz band、Max 54Mbps BPSK/QPSK/16QAM/64QAM
	168k(CPU) 1.192M(FPGA1)/2.668M(FPGA2)
	22621 (Xilinx VertexII)
Digital terrestrial TV	VHF/UHF band、21.47Mbps 64QAM-OFDM(13segment)
	2.668M (FPGA1)/2.668M(FPGA2)
	39794 (Xilinx VertexII)

form. The details of the relevant software components are presented in [5]. The software may be freely modified according to user needs, information on radio propagation paths, and so on.

In addition to the W-CDMA and the IEEE802.11a/b systems—those currently requiring the largest signal processing capacity—we have also realized a software module for a digital terrestrial TV system (consisting of 13 segments). The relevant specifications and capacity realized to date are shown in Table 2 (IEEE802.11b not included).

4 Software installation method

The installation methods of the software for this platform will be explained below, with reference to Fig. 5. The term "installation" here will refer to the process of storing the software module for implementing the communication system in the radio terminal so that it is ready for use. The communication system selected—based on factors such as the radio propagation path conditions, etc.—will be downloaded to the FPGA and CPU at the specified time. The term "software" will be used to refer collectively to the programs for the FPGA, CPU, and RF boards. The information regarding correspondence between the RF module and the relevant communication systems will be written to the RF board, and this information will be stored in the memory of the software defined radio terminal upon start-up of the unit, similar to the BIOS check performed upon startup of a PC.

(1) Insert the compact flash (CF) software into the CF interface within the CPU board.

(2) Click on the controller icon on the display unit and click "download" on the main screen.

(3) When the menu shown in Fig. 5 has been activated, the list of software module contained in the CF will be displayed in the "Protocol in CF" box 1). Select one and press the "INSTALL" button 2). The status of installation will be shown in 5).

(4) The software will be written to the flash ROM and displayed in the "Protocol in Flash ROM" box 3).

(5) Information on the RF boards connected to the software defined radio terminal upon startup can be viewed on the left in 6). To display the screen at the bottom of Fig. 5, click on the button 6) next to each board. Here, the user can input the order of priority of software module for each RF board. After completing the settings, return to the installer screen to end the installation program, and then restart the software radio.

The software module consists of the FPGA program, which mainly carries out the functions on the physical layer, the CPU program, which features the interface for the MAC layer and above, and the program for the RF board settings. The software module that consists of these three types of software programs, which together implement the communication system, are sometimes referred to as "Waveform" software. Even when installed, the software module does not run constantly, and is managed by a software platform consisting of multiple managers, as shown in Fig. 6. The Waveform manager is composed of a number of elements: the Waveform selection manager, which selects the Waveform to use based on information concerning the radio wave use conditions acquired for the Waveform being used; the Waveform control manager, which manages the information acquired by the Waveform selection manager and performs installation and uninstallation of the Waveform software; the Waveform boot manager, which inputs the communication system selected by the Waveform selection manager to the FPGA, CPU, and RF boards and starts up the system; and the Waveform view manager, which displays the various information acquired by the Waveform selection manager. After the software defined radio terminal is activated following software installation, the Waveform selection manager is launched and the radio wave use conditions are assessed by the RF board. When the measured value attains a preset threshold level for received power, the software is downloaded to the FPGA and CPU to be used at the specified time, according to the order of priority set by the user. Thus, communication is realized with the selection of a system satisfying the preferences of the user. Further, the switch between communication systems may be made not only automatically but also manually, enabling

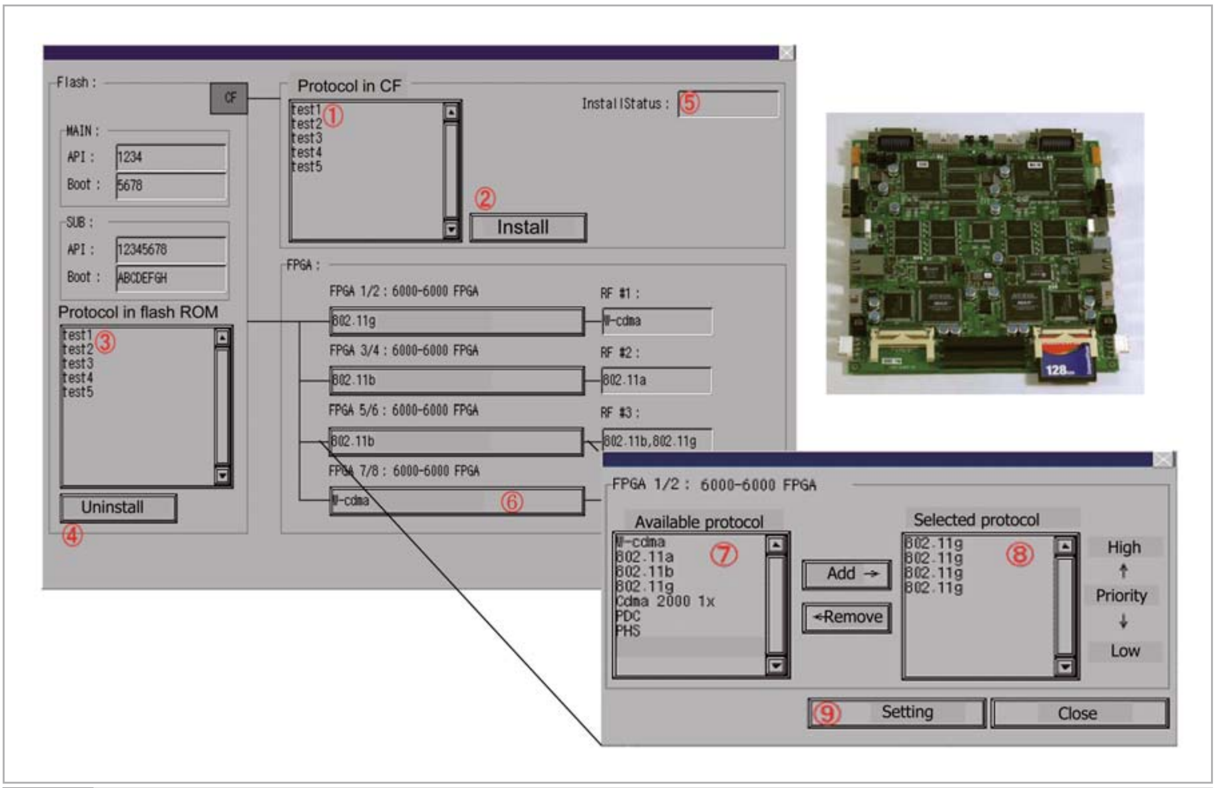

Fig.5 Software installer screen

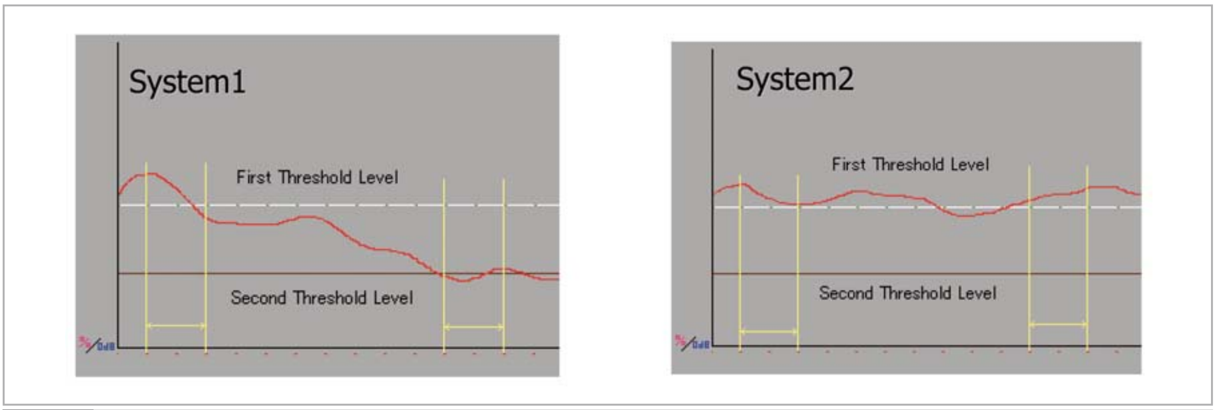

Fig.6 Scheme of the software platform

receipt of digital terrestrial TV broadcasting by manual operation at the users' discretion.

In the above scenario, received power was used as the criteria for system switchover. However, it is also possible to use bit-error rates and frame-error rates as criteria, since the differences between the communication systems are merely software-based. In short, the state of radio wave use in the system then in use is measured as shown in Fig. 7. If the received power for the system in use (in Fig. 7, this is assumed to be System 1) falls below the first threshold level, search is initiated on the radio wave use conditions of the system having the next highest priority (in Fig. 7, this is assumed to be System 2), and the unit will enter standby to await switchover at any moment. When the conditions of use deteriorate for System 1 and the received power falls below the second threshold level, the software is switched so that a system with fair communication conditions is always selected.

5 Summary of the demonstration

Using the present prototype software defined radio terminal, it is possible to perform the demonstration experiments shown on the left-hand side of Fig. 8. The first demonstration is for the handover of connections between heterogeneous systems (W-CDMA and IEEE802.11a). In this example, the variable resistor is first set to select W-CDMA. Then it is adjusted to decrease the resistance for W-CDMA and to increase that for the wireless LAN, thus automatically establishing connection to the wireless LAN. In both cases, video and still-image communication and audio communication using VoIP are enabled. The second demonstration of simultaneous communication is presented on the right-hand side of Fig. 8. In this case, software module for digital terrestrial TV broadcasting is initially activated, and then a wireless LAN system such as IEEE802.11b is activated to operate simultaneously. This process enables the

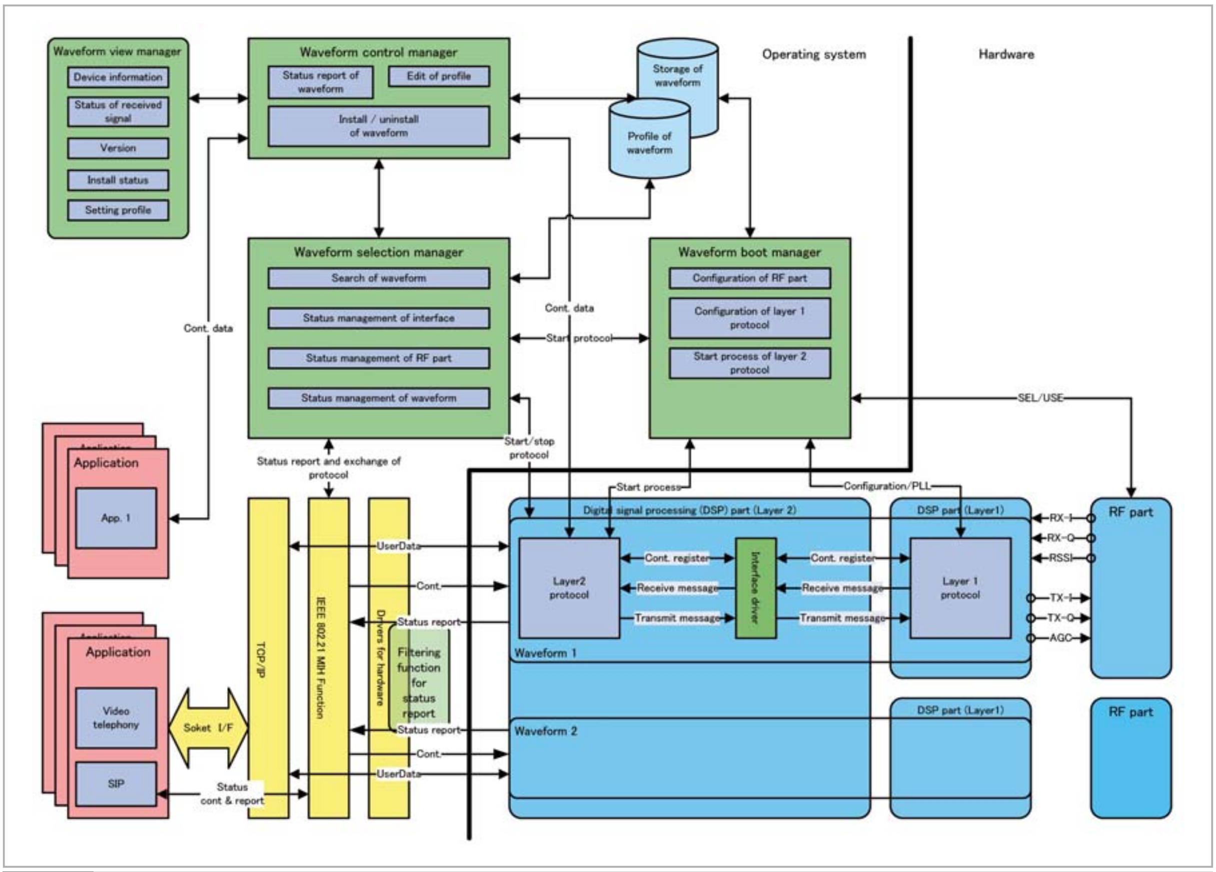

Fig.7 Method of switchover between systems

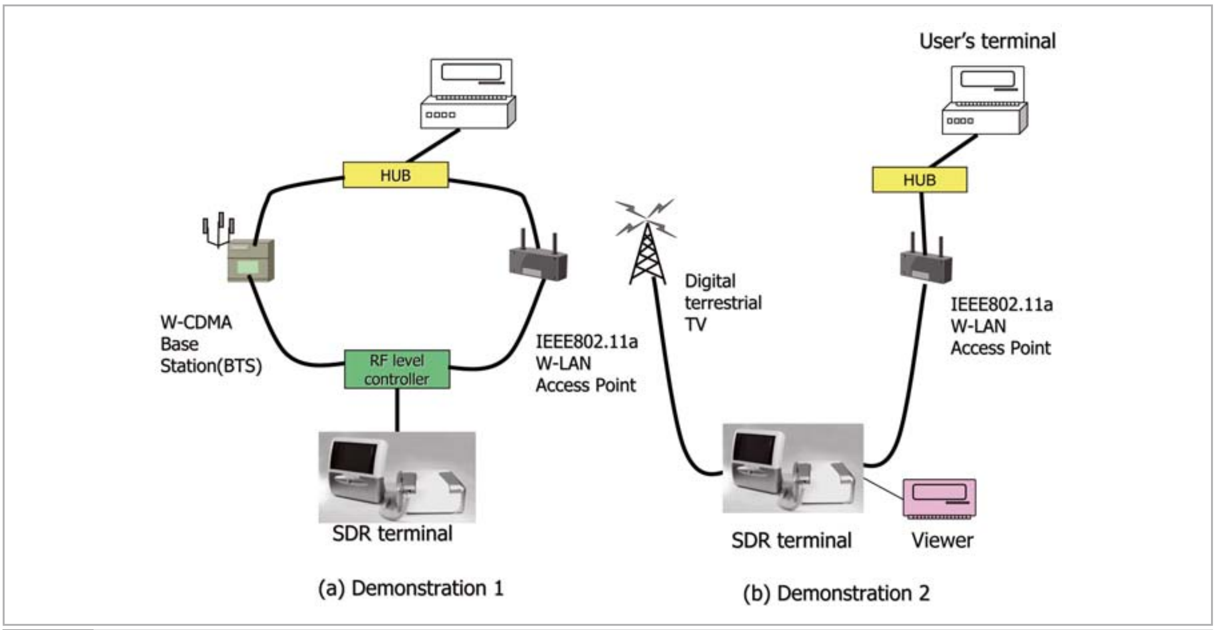

Fig.8 *Scheme of the demonstrations*

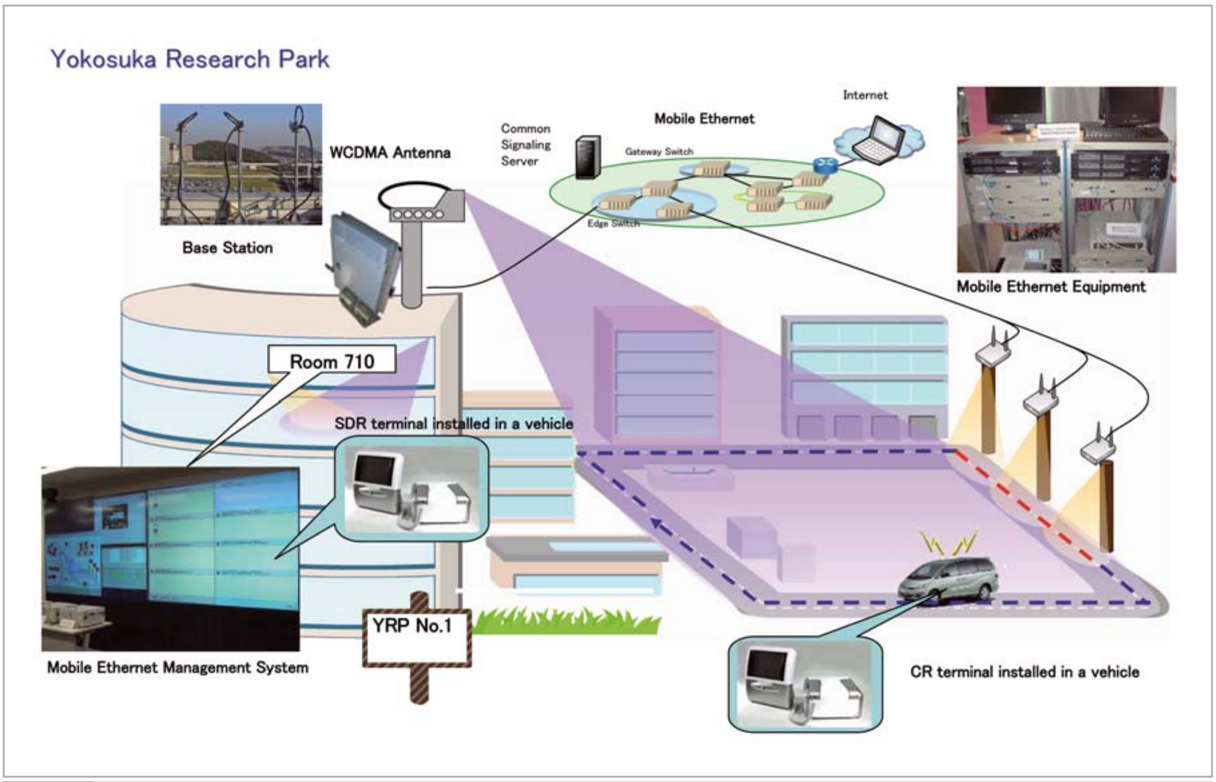

Fig.9 *Scheme of the field demonstration*

user to receive both digital terrestrial TV broadcasting and web TV simultaneously, or to use the wireless LAN to search for information on the web while watching TV.

The demonstration shown on the right-hand side of Fig. 8 has also been conducted in open air. The prototype software radio terminal (shown on Fig. 9) was installed in a vehicle for an experiment conducted at the Yokosuka Research Park, designed to verify that constant, high-quality transmissions are possible using the present prototype unit through appropriate switching between wireless LAN and W-CDMA base stations erected for the experiment. Note that in this experiment it was necessary for the IEEE802 wireless LAN system and the W-CDMA network to be integrated and connected on the network side. The Mobile Ethernet[7] developed by NICT was used in this demonstration.

6 Conclusions

The present article has presented a summary of a software defined radio terminal for a new-generation mobile communication system that enables seamless communication between multiple communication systems. The software modules prepared for the present software defined radio terminal included those for current communication/broadcasting systems that demand the largest signal processing capacities, such as W-CDMA, IEEE802.11a/b, and digital terrestrial TV. The software modules operate on a general-purpose OS μITRON and an open platform hardware offering mechanisms essential to the new-generation mobile communication system. Our software defined radio terminal prototype is the first in the world to have both cellular and wireless communication units that feature, in software form, all processing below the TCP/IP layer, thus enabling both connection between heterogeneous communication systems and simultaneous communication. Further, it is also the first radio unit in the world to support digital terrestrial TV broadcasting. In the future, we plan to re-examine the signal-processing algorithm, improve the wideband performance of the RF boards, and produce a more compact design for the software radio terminal.

References

1 http://www.soumu.go.jp/s-news/2004/040331_13.html

2 Special Issue on Globalization of Software Radio, IEEE Commun. Mag., Feb. 1999.

3 H. Harada, Y. Kamio, M. Fujise “A New Multi-mode & Multi-service Software Radio Communication System for Future Intelligent Transport Systems”, Technical Report of IEICE, SR99-12, pp.81-88, Nov. 1998.

4 H. Harada, “A Proposal of Multi-mode & Multi-service Software Radio Communication Systems for Future Intelligent Telecommunication Systems”, Proc. of WPMC’99, pp.301-304, Sep. 1999.

5 H. Harada, “Software defined radio prototype for W-CDMA and IEEE802.11a wireless LAN”, 2004 IEEE 60th Vehicular Technology Conference (VTC2004-Fall), vol.6, pp.26-29, Sep. 2004.

6 H. Harada, “Software defined radio prototype toward Cognitive Radio Communication Systems”, IEEE Dyspan 2005, vol.1, pp.539-547, Nov. 2005.

7 M. Kuroda and G. Miyamoto, “Mobile Ethernet and its security toward ubiquitous network”, Proc. WPMC’05, Aalborg, Denmark, Sep. 2005.

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Cognitive Radio, Software Defined Radio, Broadband Wireless Access System